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REVIEW

Textile dye wastewater characteristics and constituents of synthetic effluents: a critical review

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Abstract

Textile industries are responsible for one of the major environmental pollution problems in the world, because they release undesirable dye effluents. Textile wastewater contains dyes mixed with various contaminants at a variety of ranges. Therefore, environmental legislation commonly obligates textile factories to treat these effluents before discharge into the receiving watercourses. The treatment efficiency of any pilot-scale study can be examined by feeding the system either with real textile effluents or with artificial wastewater having characteristics, which match typical textile factory discharges. This paper presents a critical review of the currently available literature regarding typical and real characteristics of the textile effluents, and also constituents including chemicals used for preparing simulated textile wastewater containing dye, as well as the treatments applied for treating the prepared effluents. This review collects the scattered information relating to artificial textile wastewater constituents and organises it to help researchers who are required to prepare synthetic wastewater. These ingredients are also evaluated based on the typical characteristics of textile wastewater, and special constituents to simulate these characteristics are recommended. The processes carried out during textile manufacturing and the chemicals corresponding to each process are also discussed.

Keywords Chemicals · Contamination · Ecosystem · Effluent · Pollution · Technology · Treatment

Introduction

Background

Textile industries positively affect the economic development worldwide. China is the most important exporter of all types of textiles, followed by the European Union, India and then the USA (Ghaly et al. 2014). However, one of the problems associated with textile factories is the unacceptable effluent, especially dyes, which are difficult to degrade.

The classification of textile industries depends on the type of fabrics they produce, including cellulosic materials obtained from plants (e.g. cotton, rayon and linen), protein fabrics, which come from animals (e.g. wool, silk and mohair), and synthetic fabrics produced artificially (e.g. nylon, polyester and acrylic). Fibre production in textile factories includes dry and wet processes. The wet process uses a considerable quantity of potable water and releases highly contaminated wastewater. This process consists of sizing, de-sizing, sourcing, bleaching, mercerising, dyeing, printing and finishing techniques (Babu et al. 2007; Liu et al. 2010). Figure 1 shows the main pollutants in the wastewater discharge from each step, as indicated by Holkar et al. (2016).

The dyeing process is an important step in textile manufacturing. During this stage, the colour is added to the fibres, and different chemicals may be used to improve the adsorption process between colour and fibres. When the final product is ready after the finishing process, some of these dyes and chemicals become part of the textile industry

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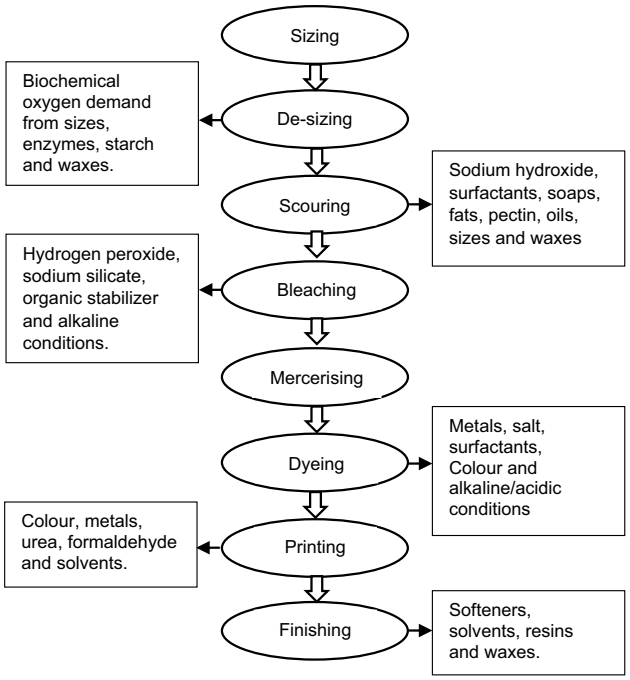

Fig. 1 The main pollutants discharged from each step of textile wet processing (after Holkar et al. (2016))

effluents (Carmen and Daniela 2012). These dyes and chemicals, in addition to their unacceptable appearance and toxic effect after their breakdown, may contaminate the nearby soil, sediment and surface water, becoming a major global environmental pollution challenge. The treatment of textile effluents is necessary to protect the ecosystem and enable subsequent recycling of the treated effluent for irrigation purposes or reuse within the textile factory processes. However, the examination of different pilot-scale treatment systems remains problematic due to the absence of a permanent source of real wastewater. Therefore, more attention needs to be paid to preparing synthetic wastewater, which simulates discharged effluents from textile factories.

Rationale, aim and objectives

Researchers have prepared and tested different constituents simulating actual wastewater discharged from textile factories. However, the attention given to artificial textile wastewater remains limited. Furthermore, the reported wastewater components are yet to be summarised and evaluated in one single reference. Synthetic wastewater is necessary for application in pilot-scale studies and when real stable effluents are not available.

The overall aim of this review is to collect and evaluate the scattered information regarding artificial textile wastewater constituents. The objectives are to (a) summarise the available typical characteristics of textile effluents; (b) summarise the available characteristics of real textile wastewater; (c) present the processes applied in textile factories and the related chemicals used in each step; (d) summarise the constituents used for preparing artificial textile wastewater and their treatment; and (e) propose suitable constituents matching the typical characteristics of textile effluents.

Real textile wastewater

Typical characteristics of textile effluents

The effluents discharged from textile factories are a mixture of dyes, metals and other pollutants. The colourants can be divided into natural and synthetic dyes. The synthetic dyes are produced easily, in different colours, and characterised by their fastness, which makes them more widely used than natural dyes (Khehra et al. 2006). Synthetic dyes are classified into different groups according to their chemical structure (e.g. azo, anthraquinone, sulphur, phthalocyanine and triarylmethane) and according to their mode of application (e.g. reactive, direct, disperse, basic and vat dying) (Popli and Patel 2015).

The dye effluents are high in colour, pH, suspended solids (SS), chemical oxygen demand (COD), biochemical oxygen demand (BOD) (Yaseen and Scholz 2016), metals (Sharma et al. 2007; Sekomo et al. 2012), temperature (Dos Santos et al. 2007; Shah et al. 2013) and salts. Therefore, during the treatment processes, it is important to monitor and compare these parameters with the standard concentrations before discharging the corresponding effluent to the receiving water body. Monitoring of the treatment performance regarding other parameters such as total organic carbon (TOC), ammonia–nitrogen (NH_4–N), nitrate–nitrogen (NO_3–N) and orthophosphate–phosphorus (PO_4–P) is also required.

Table 1 summarises the typical characteristics of textile wastewater according to different references, and Table 2 presents the wastewater characteristics of the main processes used in textile manufacturing. These characteristics showed differences among the values from one reference to another. As noted by Khandare et al. (2013), typical textile wastewater is difficult to define, because the textile application methods, even in the same process, are different from one industry to another.

Characteristics of the real effluent discharged from textile factories

The composition of textile industry wastewater varies from mill to mill and from country to country, depending on the process, the equipment used in the factory, type of fabric produced, chemicals applied, the weight of the fabric, season (Brik et al. 2006), and the trends in fashion (Kehinde and

Table 1 Typical characteristics of textile effluents

References	Ghaly et al. (2014)	Kehinde and Aziz (2014)	Hussein (2013)	Upadhye and Joshi (2012)	Kalra et al. (2011)	Al-Kdasi et al. (2005) and Turhan and Turgut (2009)	Eswaramoorthi et al. (2008)	Avlonitis et al. (2008)[a]
Temp. (°C)	35–45	21–62	33–45	35–45	35–45		35–45	
pH (–)	6–10	6.95–11.8	5.5–10.5	6–10	6–10	7–9	6–10	
Colour (Pt–Co)	50–2500	50–2500		50–2500	50–2500	50–2500		
COD (mg/l)	150–12,000	150–30,000	150–10,000	150–10,000	150–10,000	150–12,000	1000–1500	100
BOD (mg/l)	80–6000	80–6000	100–4000	100–4000	100–4000	80–6000	300–500	
EC (µS/cm)								1000
TS (mg/l)		6000–7000						
TSS (mg/l)	15–8000	15–8000	100–5000	100–5000	100–5000	15–8000	200–400	
TDS (mg/l)	2900–3100	2900–3100	1500–6000	1800–6000	1800–6000	2900–3100	8000–12,000	
Chlorine (mg/l)	1000–6000					1000–1600		
Chlorides (mg/l)			200–6000	1000–6000	1000–6000		3000–6000	
Free chlorine (mg/l)	< 10						< 10	
TA (mg/l) as $CaCo_3$		17–22	500–800	500–800	500–800			
TH (mg/l) as $CaCo_3$								
TKN (mg/l)	70–80	70–80	70–80	70–80	70–80	70–80		
TNK(mg/l)	10–30						10–30	
NO_3–N (mg/l)	< 5						< 5	
Free ammonia (mg/l)	< 10						< 10	
Na_2CO_3 (mg/l)								20
NaOH (mg/l)								10
NaCl (mg/l)								300
Phosphate (mg/l)	< 10							
Sulphates (mg/l)	600–1000		500–700				600–1000	
Sulphides (mg/l)			5–20					
Sulphur trioxide (mg/l)								
Oil and grease (mg/l)	10–30	5–5.5	10–50				10–30	
Dye (mg/l)								70
Zink (mg/l)	< 10		3–6				< 10	
Nickel (mg/l)	< 10						< 10	
Manganese (mg/l)	< 10						< 10	
Iron (mg/l)	< 10						< 10	
Copper (mg/l)	< 10		2–6				< 10	
Boron (mg/l)	< 10						< 10	
Arsenic (mg/l)	< 10						< 10	
Silica (mg/l)	< 15						< 15	
Mercury (mg/l)	< 10						< 10	
Fluorine (mg/l)	< 10						< 10	
Chromium (mg/l)			2–5					
Potassium (mg/l)			30–50					
Sodium (mg/l)	7000		400–2175	610–2175	610–2175		7000	

COD chemical oxygen demand, *BOD* 5-day biochemical oxygen demand, *TOC* total organic carbon, *EC* electrical conductivity, *TS* total solids, *TSS* total suspended solids, *TDS* total dissolved solids, *TVS* total volatile solids, *TA* total alkalinity, *TH* total hardness, *TKN* total kjeldahl nitrogen, *TN* total nitrogen, *NO_3–N* nitrate–nitrogen, *Na_2CO_3* sodium carbonate, *NaOH* sodium hydroxide and *NaCl* sodium chloride

[a]Tsypical cotton dye industry effluent

Table 2 Characteristics of textile wastewater according to process

References	Process	pH (–)	Colour (ADMI)	TSS (mg/l)	TS (mg/l)	TDS (mg/l)	COD (mg/l)	BOD (mg/l)	Chlorides as Cl^- (mg/l)	Salinity (mg/l)	NH_4 (mg/l)	NO_2 (mg/l)	NO_3–N (mg/l)
Carmen and Daniela (2012)	Desizing				16,000–32,000		4600–5900	1700–5200					
	Scouring	10–13	694		7600–17,400		8000	100–2900					
	Bleaching	8.5–9.6	153		2300–14,400	4800–19,500	6700–13,500	100–1700					
	Mercerising	5.5–9.5			600–1900	4300–4600	1600	50–100					
	Dyeing	5–10	1450–4750		500–14,100	50	1100–4600	10–1800					
Zhang et al. (2012)	Bleaching	9.4	17				528 ± 7.9						
	Fibre scouring	7.3	21							2000			
	Rinsing	8.6	7				311 ± 2.1			2000			
	Soaping	12	38				578 ± 23.5			5000			
Savin and Butnaru (2008)	Burning	5–6.5		105–936			1512–7802	675–925	64–169		3–7.9	0.08–2.5	0.025–5.3
	Bleaching	7–12.4		56–147			1060–6556	80–520	40–175		2.15–18.6	0.025–12.8	3.3–9.4
	Dyeing	6.3–10.7		72–956			258–1970.6	70–300	48–601		0.48–33.3	0.08–1.32	3.7–8.3
	Dyeing Gauge	6.5–12.1		175–325			458–7561	230–410	70–230		18.4–18.8	0.19–0.21	4.7–4.8
	Dressing	7–7.11		135–544			825–1905	60–180	40–80		5.06–14.8	1–2.2	1.6–3.6

ADMI the American Dye Manufactures Institute unit, *TSS* total suspended solids, *TDS* total dissolved solids, *TS* total solids, *COD* chemical oxygen demand, *BOD* biochemical oxygen demand, NH_4 ammonia, NO_2 nitrite and NO_3–*N* nitrate nitrogen

Aziz 2014). Table 3 shows the reported actual textile effluent characteristics belonging to different sources and countries. Some of these real effluent characteristics were not within the typical range of values given in Table 1, demonstrating the wide range of variety of real wastewater. This may be because these effluents are related to a particular step in the textile industrial processes or passed from a specific treatment stage. Metal contamination in textile effluents occurs due to the presence of dyes and additives used (e.g. caustic soda, sodium carbonate and salts) during the textile manufacturing steps. The main metals, which cause environmental challenges, are chromium, zinc, iron, mercury and lead (Hussein 2013). However, Adinew (2012) reported that the main metals found within the dye chromophores in textile effluents are cobalt, copper and chromium. The concentrations of the main heavy metals and trace elements in real textile wastewater are presented in Table 4.

Dye concentrations in textile wastewater are reported over a wide range of values. Laing (1991) indicated that the dye level in the textile effluent is 10–50 mg/l. However, the reactive dyes in cotton factories are reportedly discharged at a concentration of 60 mg/l (Shelley 1994) and a concentration between 100 and 200 mg/l (Gahr et al. 1994). Vandevivere et al. (1998) referred to dye effluents ranging between 600 and 800 mg/l. A concentration of the reactive dye effluent of 7000 mg/l was reported by Koprivanac et al. (1993). This concentration is extremely high, compared to other references, and may refer to effluent discharge from a specific textile industry. Abid et al. (2012) reported outflow dye concentrations ranging between 20 and 50 mg/l from 14 Ramadhan textile industries in Iraq. Sivakumar (2014) mentioned that the outflow concentration of the dye Acid Orange 10 from the final clarifier of a textile factory in India is 45 mg/l. However, Ghaly et al. (2014) mentioned that the dye concentrations discharged from dye houses ranged from 10 to 250 mg/l. Depending on the American Dye Manufactures Institute (ADMI), the intensity of the dye in the coloured effluents was reported to be between 1000 and 1500 ADMI units (O'Neill et al. 1999).

Methods applied for treating the characterised real textile effluents

The textile industry uses a large quantity of potable water for fibre production, and consequently releases huge amounts of wastewater (Sivakumar 2014). It is estimated that approximately 200 l of water are applied in the production of 1 kg of textile material. This amount of water is required when chemicals are applied on the fabrics and during the rinsing process of the final products (Ghaly et al. 2014). So, treatment and recycling of the textile effluents are recommended. This section surveys the methods applied to treat the actual textile wastewater characterised in Table 3 with attention given to dye removal processes in the systems.

Lin and Lin (1993) treated real textile wastewater using ozonation, coagulation and the activated sludge process in multiple reactors for effluents received from different dyeing and finishing plants in northern Taiwan. Results showed that a combination of these processes was effective in dye and COD removals.

Georgiou et al. (2002) treated real textile effluents using an ultraviolet reactor with hydrogen peroxide for effluents collected from the equalisation tank near to the Komotini (Greece) cotton textile industry. The system was successful for complete degradation and mineralisation of Levafix and Remazol dyes.

Brik et al. (2006) evaluated the efficiency of membrane bioreactor technology for the treatment of mixed actual textile effluents supplied from the finishing industry for polyester production. The system was able to remove around 87% of the colour, and the authors suggested that a polishing step is necessary when a treatment objective is also for reusable purposes.

Chatzisymeon et al. (2006) examined the electrochemical oxidation method using a titanium–tantalum–platinum–iridium anode for treatment of real textile wastewater supplied by Epilektos (textile factory in Sterea, Central Greece). In this case study, the effluents were collected from the equalisation tank, and contained dyes, sodium hydroxide, sodium sulphate and sodium carbonate, as well as detergents, and softening, dispersing and fixing agents. The treatment performance was affected by the applied current, pH, electrolyte type and concentrations, and the water bed. The results indicated good efficiency regarding dye chromophore degradation with a moderate level of mineralisation.

Avlonitis et al. (2008) treated real effluents from a cotton dye factory by the nanofiltration membrane technique, which provided complete decolourisation of the dye reactive black 5 (RB5) and complete organic matter removal with around 72% salt reduction. Bulc and Ojstršek (2008) operated a pilot-scale combined vertical-flow and horizontal-flow constructed wetland (CW) system planted with *Phragmites australis* (Cav.) Trin. ex Steud. (common reed) for the treatment of real textile wastewater received from a cotton-processing textile mill. The results achieved by this CW showed high pollutant removal efficiencies, which could suggest a simple, effective and cheap system for achieving environmental legislation requirements.

Lim et al. (2010) evaluated the potential of a high rate pond system using *Chlorella* spp. Beij. for textile wastewater treatment. The effluent was collected from a holding tank (last process of textile wastewater treatment before discharge) of a garment factory in Malaysia. The authors suggested that the system was effective as a polishing step for treating wastewater after final release. Bes-Piá et al. (2010)

Table 3 Reported real textile effluent characteristics from different sources and countries

References	Almazán-Sánchez et al. (2016)	Bhuvaneswari et al. (2016)	Tomei et al. (2016)	Buscio et al. (2015)	Kaur and Sharma (2015) and Singh et al. (2013)	Punzi et al. (2015)
Source	Textile effluents from rinsing step of a denim textile industry	Textile industry effluents limits of three samples	Textile effluents from dyeing bath	Textile effluents from dyeing process	Range of seven woven and knit textile mills of finishing industry	Real textile wastewater from a textile factory in Tirupur
Country	Mexico	India	Italy	Spain	India	India
Temp. (°C)		28–29				
46	28–30					
pH (–)	6.84	8.6–9.2	9 ± 0.5	6.9	4.3–11.9	10
Colour (Pt–Co)	330		0.66 ± 0.06[a]	300		
COD (mg/l)	344	3880–4400	1017 ± 58	806	195–3050	1714
BOD (mg/l)	91.91	1206–1750	9.8 ± 1.3		108–790	
TOC (mg/l)	84.92		158.0 ± 9.8		101–7784	
EC (μS/cm)	471.3			1825		12,500
TS (mg/l)		2670–2850			450–6510	
TSS (mg/l)		550–650		112	0.535 ± 0.1	
TDS (mg/l)		2070–2200			430–49,440	
TVS (mg/l)						
DS (mg/l)						
MLSS (mg/l)						
Turbidity (NTU)	104.66	12.5–16.6				
DO (mg/l)						
Chlorides as Cl^- (mg/l)	338.19	4005–4320	38.6 ± 3.1	270		
Free chlorine (mg/l)						
TA (mg/l) as $CaCo_3$	83.25			150		
TH (mg/l) as $CaCo_3$	119.17	1750–1900		50		
TN (mg/l)						
NO_3–N (mg/l)	1.9		3.8 ± 0.1			3.6
NO_2–N (mg/l)						
Free ammonia (mg/l)						
NH_4–N (mg/l)			40.01 ± 4.5			1.7
NH_3–N (mg/l)		73–85.6				
Na_2SO_4 (mg/l)						
Na_2CO_3 (mg/l)						
NaOH (mg/l)						
Carbonate (mg/l)	0.035					
Bicarbonate (mg/l)	101.5					

Table 3 (continued)

References	Almazán-Sánchez et al. (2016)	Bhuvaneswari et al. (2016)	Tomei et al. (2016)	Buscio et al. (2015)	Kaur and Sharma (2015) and Singh et al. (2013)	Punzi et al. (2015)
Source	Textile effluents from rinsing step of a denim textile industry	Textile industry effluents limits of three samples	Textile effluents from dyeing bath	Textile effluents from dyeing process	Range of seven woven and knit textile mills of finishing industry	Real textile wastewater from a textile factory in Tirupur
Country	Mexico	India	Italy	Spain	India	India
Total phosphor (mg/l)						
Phosphate (mg/l)	287.08	72.8-86.8	3.2 ± 0.1			16.8
Sulphates (mg/l)	227.06	2050–2250	4.5 ± 0.1	387		
Sulphides (mg/l)						
Sulphur trioxide (mg/l)						
AOX (mg/l)						
Acidity (mg/l)	20.75					
Phenol (mg/l)						
Oil and grease (mg/l)						
Dye (mg/l)						
EC50 (%)						

References	Manekar et al. (2014)	Manekar et al. (2014)	Sun et al. (2014)	Uysal et al. (2014)	Al-Shuwaik et al. (2013)
Source	Raw textile wastewater	Raw textile wastewater passing from an equalisation tank	Textile dye wastewater from Jinyang textile industry	Real wastewater from textile factory in Bursa city	Textile wastewater from Al-Hilla factory
Country	India	India	China	Turkey	Iraq
Temp. (°C)	43–46				
pH (–)	7.8–9	7.7–8.0	7.4–7.9	8.22 ± 0.5	7.9–8.5
Colour (Pt–Co)	25–260[b]	240–290[b]		2200 ± 800	85
COD (mg/l)	752–1120	678–932	1114–1350	300 ± 100	80–90
BOD (mg/l)	368–458[c]	272–310			50–60
TOC (mg/l)					
EC (µS/cm)					
TS (mg/l)					
TSS (mg/l)	120–170	120–180			312–400
TDS (mg/l)	1670–2040	1632–1902			1340–1350
TVS (mg/l)					
DS (mg/l)					
MLSS (mg/l)				165 ± 80	
Turbidity (NTU)			125–137		

Table 3 (continued)

References	Manekar et al. (2014)	Manekar et al. (2014)	Sun et al. (2014)	Uysal et al. (2014)	Al-Shuwaik et al. (2013)
Source	Raw textile wastewater	Raw textile wastewater passing from an equalisation tank	Textile dye wastewater from Jinyang textile industry	Real wastewater from textile factory in Bursa city	Textile wastewater from Al-Hilla factory
Country	India	India	China	Turkey	Iraq
DO (mg/l)					
Chlorides as Cl^- (mg/l)	384–452	384–412			542–550
Free chlorine (mg/l)					
TA (mg/l) as $CaCo_3$	480–510	460–500			
TH (mg/l) as $CaCo_3$					
TN (mg/l)					
NO_3–N (mg/l)					
NO_2–N (mg/l)					
Free ammonia (mg/l)					
NH_4–N (mg/l)					
NH_3–N (mg/l)	5–10	4–8			
Na_2SO_4 (mg/l)					
Na_2CO_3 (mg/l)					
NaOH (mg/l)					
Carbonate (mg/l)					
Bicarbonate (mg/l)					
Total phosphor (mg/l)					
Phosphate (mg/l)	BDL–1.8	BDL–3			
Sulphates (mg/l)	320–380	300–320			410–580
Sulphides (mg/l)					
Sulphur trioxide (mg/l)					
AOX (mg/l)					
Acidity (mg/l)					
Phenol (mg/l)					
Oil and grease (mg/l)					
Dye (mg/l)					
EC50 (%)					

Table 3 (continued)

References	Al-Shuwaiki et al. (2013)	Hussein (2013)	Qian et al. (2013)	Sivakumar et al. (2013)	Un and Aytac (2013)	Abid et al. (2012)
Source	Textile wastewater from Al-Khadimia factory	Real textile wastewater	Textile wastewater passed from activated sludge unit	Textile wastewater from the final clarifier of textile industrial effluent treatment plant	Wastewater from textile factory in Eskisehir	Raw textile wastewater from 14-Ramadhan textile mill
Country	Iraq	Iraq	China	India	Turkey	Iraq
Temp. (°C)						
pH (–)	7–9.5	12.9	8.0–8.3		9.01	5–8
Colour (Pt–Co)	50–65		310–325[d]			
COD (mg/l)	120–140	225.084	61–75	3458	1953	
BOD (mg/l)	15–20	149.3	6–10	2895		
TOC (mg/l)						
EC (μS/cm)				4856	739	700–1300
TS (mg/l)						
TSS (mg/l)	200–300					
TDS (mg/l)	600–730			3108		400–1000
TVS (mg/l)						
DS (mg/l)						
MLSS (mg/l)						
Turbidity (NTU)	26–30		40–61			
DO (mg/l)						
Chlorides as Cl- (mg/l)	120–140	63.91		942		
Free chlorine (mg/l)						
TA (mg/l) as $CaCo_3$		73.68	102.5–109.2			
TH (mg/l) as $CaCo_3$		237				
TN (mg/l)						
NO_3–N (mg/l)						
NO_2–N (mg/l)						
Free ammonia (mg/l)						
NH_4–N (mg/l)						
NH_3–N (mg/l)						
Na_2SO_4 (mg/l)						
Na_2CO_3 (mg/l)						

Table 3 (continued)

References	Al-Shuwaiki et al. (2013)	Hussein (2013)	Qian et al. (2013)	Sivakumar et al. (2013)	Un and Aytac (2013)	Abid et al. (2012)
Source	Textile wastewater from Al-Khadimia factory	Real textile wastewater	Textile wastewater passed from activated sludge unit	Textile wastewater from the final clarifier of textile industrial effluent treatment plant	Wastewater from textile factory in Eskisehir	Raw textile wastewater from 14-Ramadhan textile mill
Country	Iraq	Iraq	China	India	Turkey	Iraq
NaOH (mg/l)						
Carbonate (mg/l)						
Bicarbonate (mg/l)						
Total phosphor (mg/l)						
Phosphate (mg/l)	0.64					
Sulphates (mg/l)	140–200			758		
Sulphides (mg/l)						
Sulphur trioxide (mg/l)						
AOX (mg/l)						
Acidity (mg/l)						
Phenol (mg/l)				155		
Oil and grease (mg/l)						
Dye (mg/l)				45	0.337[a]	
EC50 (%)						

References	Aouni et al. (2012)	Imtiazuddin et al. (2012)	Joshi and Santani (2012)	Nopkhuntod et al. (2012)	Nopkhuntod et al. (2012)
Source	Raw textile wastewater from the rinsing baths of Colortex textile industry	Range of raw textile wastewater from 7 textile mills from different steps	Raw textile wastewater from Sumukh textile mill collected from 6 sites	Actual textile wastewaters from dyebath wastewater	Raw textile wastewater from equalising tank
Country	Spain	Pakistan	India	Thailand	Thailand
Temp. (°C)		36–49.2	31.53–50.67		
pH (–)	7.11	7.5–11.5	9.17–12.7		
Colour (Pt–Co)				2,502,000 ± 500	2105 ± 13
COD (mg/l)	708	115.66–705.25	449.50–2078.55	45,500 ± 182	2600 ± 3.78
BOD (mg/l)		125.55–653.75	71.75–852.63	5 ± 0.00	520 ± 0.47
TOC (mg/l)					
EC (μS/cm)	3840	175.7–345.0	1340–6550		
TS (mg/l)					
TSS (mg/l)		934–1619	419.87–1549	45 ± 0.73	130 ± 0.85

Table 3 (continued)

References	Aouni et al. (2012)	Imtiazuddin et al. (2012)	Joshi and Santani (2012)	Nopkhuntod et al. (2012)	Nopkhuntod et al. (2012)
Source	Raw textile wastewater from the rinsing baths of Colortex textile industry	Range of raw textile wastewater from 7 textile mills from different steps	Raw textile wastewater from Sumukh textile mill collected from 6 sites	Actual textile wastewaters from dyebath wastewater	Raw textile wastewater from equalising tank
Country	Spain	Pakistan	India	Thailand	Thailand
TDS (mg/l)	3137	2469–7295	1235.58–4975.2	45,000 ± 123	5600 ± 6.54
TVS (mg/l)					
DS (mg/l)					
MLSS (mg/l)					
Turbidity (NTU)	4.02				
DO (mg/l)					
Chlorides as Cl- (mg/l)	> 125				
Free chlorine (mg/l)					
TA (mg/l) as $CaCo_3$					
TH (mg/l) as $CaCo_3$					
TN (mg/l)					
NO_3–N (mg/l)					
NO_2–N (mg/l)					
Free ammonia (mg/l)					
NH_4–N (mg/l)					
NH_3–N (mg/l)					
Na_2SO_4 (mg/l)					
Na_2CO_3 (mg/l)					
NaOH (mg/l)					
Carbonate (mg/l)					
Bicarbonate (mg/l)					
Total phosphor (mg/l)					
Phosphate (mg/l)					
Sulphates (mg/l)	28				
Sulphides (mg/l)					
Sulphur trioxide (mg/l)					
AOX (mg/l)					
Acidity (mg/l)					
Phenol (mg/l)					
Oil and grease (mg/l)					
Dye (mg/l)					
EC50 (%)					

Table 3 (continued)

References	Nopkhuntod et al. (2012)	Paul et al. (2012)	Syafalni et al. (2012)	Bes-Piá et al. (2010)	Lim et al. (2010)	Bulc and Ojstršek (2008)
Source	Actual textile wastewaters from textile industry from activated sludge treatment unit	Range of 6 textile industries effluent	Dye wastewater taken from Penfabric Mill	Textile mill wastewater from secondary treatment plant in the rinsing process	Textile wastewater from a garment factory	Real textile wastewater
Country	Thailand	India	Malaysia	Spain	Malaysia	
Temp. (°C)					35–58	30–38
pH (–)		7.54–9.59	9–10.18	7.6–7.8	3.85–11.4	8–9
Colour (Pt–Co)	420 ± 3		680–750	0.39–0.54[a]	76–1777.33	
COD (mg/l)	750 ± 1.67	381–1548	298–360	200–315	231.67–990	276–1379
BOD (mg/l)	25 ± 0.04	130–500				99–350
TOC (mg/l)						74–530
EC (μS/cm)				2600–2800	690–1381	2050–6430
TS (mg/l)					39.33–11,689.33	
TSS (mg/l)	90 ± 0.33		0.0076	15–46	22.67–150	27–408
TDS (mg/l)	4800 ± 15.00	2264–7072		1456–1568	14.00–11,564	
TVS (mg/l)					54.46–531	
DS (mg/l)						
MLSS (mg/l)						
Turbidity (NTU)			63–74[e]	8.2–12.6		
DO (mg/l)					1.5–7.5	1.2–1.7
Chlorides as Cl^- (mg/l)		950–2750		200–365		
Free chlorine (mg/l)						
TA (mg/l) as $CaCo_3$		280–500				
TH (mg/l) as $CaCo_3$		470–1050		133–171		
TN (mg/l)						
NO_3–N (mg/l)					1.23–5.60	
NO_2–N (mg/l)						
Free ammonia (mg/l)			2.1–3.8			
NH_4–N (mg/l)					0.47–50.83	0.2–4.5
NH_3–N (mg/l)						
Na_2SO_4 (mg/l)						
Na_2CO_3 (mg/l)						
NaOH (mg/l)						
Carbonate (mg/l)				96–96		
Bicarbonate (mg/l)				800–1000		
Total phosphor (mg/l)						

Table 3 (continued)

References	Nopkhuntod et al. (2012)	Paul et al. (2012)	Syafalni et al. (2012)	Bes-Piá et al. (2010)	Lim et al. (2010)	Bulc and Ojstršek (2008)
Source	Actual textile wastewaters from textile industry from activated sludge treatment unit	Range of 6 textile industries effluent	Dye wastewater taken from Penfabric Mill	Textile mill wastewater from secondary treatment plant in the rinsing process	Textile wastewater from a garment factory	Real textile wastewater
Country	Thailand	India	Malaysia	Spain	Malaysia	
Phosphate (mg/l)		1.6–10.45			0.07–4.01	
Sulphates (mg/l)		440–912		124–176		76–2200
Sulphides (mg/l)		12–79				
Sulphur trioxide (mg/l)						
AOX (mg/l)						
Acidity (mg/l)						
Phenol (mg/l)						
Oil and grease (mg/l)						
Dye (mg/l)						
EC50 (%)						

Source	Actual textile wastewaters from textile industry from activated sludge treatment unit	Range of 6 textile industries effluent	Dye wastewater taken from Penfabric Mill	Textile mill wastewater from secondary treatment plant in the rinsing process	Textile wastewater from a garment factory	Real textile wastewater	Mixed textile wastewater from a polyester finishing factory	Actual textile effluent from Epilektos SA manufacturing industry	Range of 6 major textile industries effluents	Cotton textile wastewater characteristics	Typical characteristics of textile wastewater
Country	Thailand	India	Malaysia	Spain	Malaysia		Austria	Greece	India	Greece	India
Temp. (°C)					35–58	30–38					289–1030
pH (–)		7.54–9.59	9–10.18	7.6–7.8	3.85–11.4	8–9	6.36–9.67	9.5	7–9	8.2	99–1010
Colour (Pt–Co)	420 ± 3		680–750	0.39–0.54[a]	76–1777.33						
COD (mg/l)	750 ± 1.67	381–1548	298–360	200–315	231.67–990	276–1379	1380–6033	404	1600–3200	150	460–1500
BOD (mg/l)	25 ± 0.04	130–500				99–350	177–720		500–1010	80	100–500
TOC (mg/l)						74–530					
EC (μS/cm)				2600–2800	690–1381	2050–6430	0.661–4.95		44,309–108,710		2100–2900
TS (mg/l)					39.33–11,689.33			75			
TSS (mg/l)	90 ± 0.33		0.0076	15–46	22.67–150	27–408	75–220		8309–101,580		91–250
TDS (mg/l)	4800 ± 15.00	2264–7072		1456–1568	14.00–11,564				40,409–107,500		

Table 3 (continued)

Source	Actual textile wastewaters from textile industry from activated sludge treatment unit	Range of 6 textile industries effluent	Dye wastewater taken from Penfabric Mill	Textile mill wastewater from secondary treatment plant in the rinsing process	Textile wastewater from a garment factory	Real textile wastewater	Mixed textile wastewater from a polyester finishing factory	Actual textile effluent from Epilektos SA manufacturing industry	Range of 6 major textile industries effluents	Cotton textile wastewater characteristics	Typical characteristics of textile wastewater
Country	Thailand	India	Malaysia	Spain	Malaysia		Austria	Greece	India	Greece	India
TVS (mg/l)					54.46–531						
DS (mg/l)									32,109–105,920		
MLSS (mg/l)											
Turbidity (NTU)			63–74[e]	8.2–12.6							
DO (mg/l)					1.5–7.5	1.2–1.7					
Chlorides as Cl^- (mg/l)		950–2750		200–365					980–2185		
Free chlorine (mg/l)											
TA (mg/l) as $CaCo_3$		280–500									
TH (mg/l) as $CaCo_3$		470–1050		133–171					120–150		
TN (mg/l)							7.53–75.2				
NO_3–N (mg/l)					1.23–5.60		0.26–11.1		120–627		
NO_2–N (mg/l)											
Free ammonia (mg/l)			2.1–3.8								
NH_4–N (mg/l)					0.47–50.83	0.2–4.5	0.76–23.7				
NH_3–N (mg/l)											
Na_2SO_4 (mg/l)								5500			
Na_2CO_3 (mg/l)								440			
NaOH (mg/l)								110			
Carbonate (mg/l)				96–96					110–120		
Bicarbonate (mg/l)				800–1000					555–1464		

Table 3 (continued)

Source	Actual textile wastewaters from textile industry from activated sludge treatment unit	Range of 6 textile industries effluent	Dye wastewater taken from Penfabric Mill	Textile mill wastewater from secondary treatment plant in the rinsing process	Textile wastewater from a garment factory	Real textile wastewater	Mixed textile wastewater from a polyester finishing factory	Actual textile effluent from Epilektos SA manufacturing industry	Range of 6 major textile industries effluents	Cotton textile wastewater characteristics	Typical characteristics of textile wastewater
Country	Thailand	India	Malaysia	Spain	Malaysia		Austria	Greece	India	Greece	India
Total phosphor (mg/l)							0.58–17.9				
Phosphate (mg/l)		1.6–10.45			0.07–4.01		0.25–5.38				
Sulphates (mg/l)		440–912		124–176		76–2200	60–294		307–620		
Sulphides (mg/l)		12–79									
Sulphur trioxide (mg/l)							0.1–73				
AOX (mg/l)							0.11–1.05				
Acidity (mg/l)											
Phenol (mg/l)											
Oil and grease (mg/l)											
Dye (mg/l)											
EC50 (%)								75			

COD chemical oxygen demand, *BOD* 5-day biochemical oxygen demand, *TOC* total organic carbon, *EC* electrical conductivity, *TS* total solids, *TSS* total suspended solids, *TDS* total dissolved solids, *TVS* total volatile solids, *DS* dissolved solids, *MLSS* mixed liquor suspended solids, *NTU* nephelometric turbidity unit, *DO* dissolved oxygen, *TA* total alkalinity, *TH* total hardness, *TKN* total Kjeldahl nitrogen, *TN* total nitrogen, NO_3–*N* nitrate nitrogen, NO_2–*N* nitrite nitrogen, NH_4–*N* ammonium nitrogen, NH_3–*N* ammonia nitrogen, Na_2SO_4 sodium sulphate, Na_2CO_3 sodium carbonate, *NaOH* sodium hydroxide, *NaCl* sodium chloride, *AOX* adsorbable organic halogens, *EC50* half maximal effective concentration and *BDL* below detected limits

[a]Abs unit, [b]Hazen units, [c]BOD3 days, [d]American dye manufacturer's institute unit, [e]formazin attenuation units

Table 4 Heavy metal and trace element concentrations (mg/l) of real textile wastewater

References	Almazán-Sánchez et al. (2016)	Bhuvaneswari et al. (2016)	Manekar et al. (2014)	Manekar et al. (2014)	Al-Shuwaiki et al. (2013)	Hussein (2013)	Aouni et al. (2012)
Source	Textile effluents from the rinsing step of a Denim textile factory	Textile industry wastewater (range for three samples)	Raw textile industry wastewater	Raw textile wastewater passing from an equalisation tank	Textile wastewater from Al-Khadimia factory	Real textile wastewater	Raw textile wastewater from the rinsing baths of a Colortex textile factory
Country	Mexico	India	India	India	Iraq	Iraq	Spain
Zinc			0.06–0.27	0.01–0.3		0.256	
Lead			0.11–0.12	0.1–0.13	1–2		
Cadmium			0.01–0.02	0.01			42
Nickel			0.08–0.3	0.07–0.26		0.104	
Cobalt			0.02–0.03	0.03–0.06			
Magnesium	4.39						18.6
Iron	0.343		0.7–1.41	1.42–8.25	0.1–1.0		
Chromium			0.03–0.05	0.04–0.07	0.1–1.0		
Copper			0.03–0.04	0.07–0.11		0.270	
Fluorine							
Lithium		68–83.6					
Silica	5.6						
Calcium	5.65	2185–2378.5					
Manganese	1.99		BDL–0.16	BDL–0.26			
Potassium	3.08	2490–2685				44.831	
Sodium	44.99	2710–2900				697.6	1008
Phosphorus							

References	Imtiazuddin et al. (2012)	Joshi and Santani (2012)	Paul et al. (2012)	Syafalni et al. (2012)	Bes-Piá et al. (2010)	Hussain et al. (2004)
Source	Range of raw textile wastewater from seven textile mills from different steps	Real effluents from Sumukh textile mill	Range of six textile industry effluents	Dye wastewater taken from Penfabric Mill	Textile mill wastewater from the rinsing process of a secondary treatment plant	Range of six major textile industry effluents
Country	Pakistan	India	India	Malaysia	Spain	India
Zinc	2.36–6.03	0.48–7.32		< 0.2		
Lead	0.16–0.35					0.011–0.061
Cadmium		0.02–0.74				
Nickel	0.66–1.53	0.06–1.16				
Cobalt						
Magnesium			88–210			13–29
Iron	1.08–3.11	0.3–111.38		0.13–0.15		0.017–0.163
Chromium	1.05–1.86	1.16–2.2		0.5–0.6		0.015–7.854
Copper	0.07–5.14	0.17–9.26		0.03		0.006–0.311
Fluorine						0.7–2.2
Lithium						
Silica						
Calcium			128–404			12–28
Manganese	0.88–1.85	0.07–7.74				0.001–0.022
Potassium		40.50–113.64			54–67	11–19
Sodium		86.32–259.06			179–190	975–2185
Phosphorus		0.17–2.35				

BDL below detection limits

treated real textile effluents, discharged from a secondary treatment plant, by nanofiltration membranes of differing characteristics for reuse purposes in the rinsing step of a textile factory. Aouni et al. (2012) treated real textile effluents, collected from rinsing baths of a textile mill in Spain, using ultrafiltration and nanofiltration techniques for reuse purposes. The results showed that these methods of treatment improved the quality of textile effluents in terms of COD and colour. In comparison, Syafalni et al. (2012) evaluated adsorption methods using granular activated carbon and zeolite filters for treatment of real textile wastewaters received from Penfabric mill (Penang, Malaysia). The dye effluents contained dying ingredients, sodium sulphate anhydride and polyvinyl alcohol. The authors concluded that best adsorption was achieved by filters including zeolite in the top layer and granular activated carbon at the bottom.

Nopkhuntod et al. (2012) studied the ability of a shale column under different conditions for treating three types of real textile wastewater supplied from the textile industry in Prachinburi Province (Thailand). The sources of these effluents were dye bath wastewater from the dyeing process, actual textile wastewater from the equalising tank after the initial process, and wastewater from the storage tank, which was treated by an activated sludge unit. The shale bed provided promising results for colour and COD removal. However, high removal efficiencies were documented for the effluent supplied from the activated sludge unit.

Al-Shuwaiki et al. (2013) studied the effect of magnesium, lime and their combination with a polyelectrolyte for different doses as coagulant materials to enhance chemical adsorption of colour and other pollutants from wastewater obtained from Al-Khadimia textile industry (Iraq). The highest treatment efficiency was obtained using magnesium mixed with polyelectrolyte. Hussein (2013) treated real textile effluents in Iraq using a photocatalytic technique with titanium dioxide and zinc oxide. A comparison of results indicated that zinc oxide outperformed titanium dioxide. In addition, the treated effluents were suitable for reuse regarding domestic, industrial and irrigation purposes. Qian et al. (2013) operated a novel hybrid system using stepwise coagulation and intermediate ozonation with granular activated carbon for the treatment of organic matter collected from an activated sludge treatment unit (Shanghai, China) for reuse purposes. The hybrid system provided promising results for wastewater recycling.

Un and Aytac (2013) examined the performance of an electrochemical reactor for treatment of real textile effluents supplied by a local factory in Eskisehir (Turkey). The outcome indicated that the electrocoagulation method was able to remove COD and colour effectively to enable reuse or direct discharge of the treated effluents. Sivakumar et al. (2013) treated raw textile effluent supplied from the final clarifier of Chennai city treatment plant (India) using a CW system planted with *Eichhornia crassipes* (Mart.) Solms ((common) water hyacinth). The results showed high improvement for water quality parameters. However, Sivakumar (2014) focused on the examination of the dye Acid Orange 7 (AO7) and COD removal from aqueous solution and real textile effluents using a wetland pond planted with *Lemna minor* L. (common duckweed). The system was able to remove more than 80% of the dye AO7.

Sun et al. (2014) treated textile dye effluent supplied from Jinyang Textile Company (Qingdao, China) using a new flocculent mixture consisting of polymeric aluminium ferric sulphate and cationic polyacrylamide. The mixture, after 30 min of settling time and using a 60-mg/l dosage at a pH value of 6.5, provided around 98% and 87% turbidity and COD removal efficiency, respectively. Uysal et al. (2014) operated a pond system planted with Duckweed for colour removal from real industrial wastewater in Turkey. The authors obtained a higher removal efficiency with a contact time of 3 days, and the removal decreased with increasing time.

Manekar et al. (2014) used a sequence of chemical coagulation-flocculation and bio-oxidation processes for purification of combined wastewater collected from different steps in the textile industry (India), including spinning, sizing, scouring, kiering and bleaching, dyeing, and printing processes. This combination provided promising results for detoxifying the textile effluent.

The treatment of real textile effluents supplied from Royal Ten Cate (Nijverdal, The Netherlands) using an anaerobic biofilm reactor followed by the ozonation technique was carried out by Punzi et al. (2015). Their study suggests that the ozonation technique could be successfully used as a post-treatment after the main biological process, for recalcitrant compound degradation. Buscio et al. (2015) treated real textile effluents from a dying process (Terrassa, Spain) using a combination of two treatment methods: homogenisation decantation and membrane treatments. The two treatment systems removed around 66% and 30% of COD and colour, respectively. Almazán-Sánchez et al. (2016) reported the characteristics of real textile effluents and focused on the adsorption process by natural and modified clay and activated carbon, which was carried out using batch and column experiments. The effluents were supplied from the rinse vat of a Denim textile manufacturing process in Mexico containing organic material and a high concentration of inorganic ions such as sulphates, phosphate and sodium that may have affected the adsorption efficiency.

Bhuvaneswari et al. (2016) analysed the characteristics of real textile effluents in India and operated a laboratory model for treatment using an anaerobic baffled reactor under different conditions. Tomei et al. (2016) treated real textile wastewater received from a dyeing bath belonging to a textile factory located in Como (Italy). The effluents contained

a mixture of three reactive dyes (remazol black 5, remazol yellow RR and remazol brilliant red 21), and chemical additions such as detergents, surfactants, salts, dispersing agents, acids and caustic soda. The authors operated anaerobic, aerobic and sequential anaerobic/aerobic processes, and they found out that the sequential anaerobic/aerobic system was best regarding the removal of colour.

Synthetic textile wastewater

Many authors have examined treatment technologies and corresponding dye removal efficiencies from either an aqueous solution or a prepared artificial textile wastewater. This is firstly due to the common absence of raw textile wastewater as a local and permanent source, and secondly to keep the composition of the untreated wastewater constant to make valid comparisons of treatment system evaluations (O'Neill et al. 1999).

Investigations have been carried out regarding the removal efficiency of different textile dyes from aqueous solutions prepared by mixing dye with tap water, deionised water or distilled water. Below are some of the reported methods used in this field.

Davies et al. (2005, 2006, 2009) assessed the performance of down-flow CW using *P. australis* for the treatment of wastewaters prepared by dissolving the dye AO7 with tap water (dye inflow concentrations were 130 and 700 mg/l). The system was successful for treating the dye AO7, and the plants played an active role in dye degradation. Chatzisymeon et al. (2006) prepared synthetic wastewater to investigate the electrochemical oxidation method for dye wastewater treatment. The composition contained 16 dyes and the total dye concentration was equal to 361 mg/l. Kashefialasl et al. (2006) treated the dye acid yellow 36 in aqueous solution by the electrocoagulation method using iron electrodes. Noonpui and Thiravetyan (2011) examined the performance of CW vegetated by *Echinodorus* spp. Richard ex Engelmann in A. Gray, 1848 (burhead) under both soil and soil-free conditions for the clarification of three reactive azo dyes of different molecular sizes: reactive red 2, reactive red 120 and reactive red 141 (RR 141) in aqueous solution. The results demonstrated that the plant was efficient at dye removal for both conditions. Shirzad-Siboni et al. (2014) studied the removal of acid blue 113 (AB113) and RB5 in aqueous solution using activated red mud as a cheap adsorbent material. Higher removal was achieved for the dye AB113. Other adsorbents have been used for dye removal such as fly ash (Sun et al. 2013) and activated carbon (Aysu and Kucuk 2015).

Textile dye removal from aqueous solution was also evaluated using plant species in batch test studies such as *Posidonia oceanica* (L.) Delile (Neptune grass) (Ncibi et al. 2007), *Calotropis procera* (Aiton) W. T. Aiton (apple of Sodom) (Ali and Muhammad 2008) and *L. minor* (Reema et al. 2011; Movafeghi et al. 2005; Salman et al. 2016).

The treatment of dyes in aqueous solutions has been applied using a wide range of different methods. However, studies using this type of wastewater are unable to provide a full understanding of the treatment performance regarding the impact of other missing contaminants (nutrients, chemicals and additives) on the removal efficiency (Gupta et al. 2015). As stated by Bulc and Ojstršek (2008), the pollutants' reduction in treatment systems depends mostly on the composition of textile wastewater, and the chemical compositions of applied organic substances in addition to other factors.

Many authors have prepared synthetic textile wastewater contaminated with textile dyes, which have been arranged by mixing the dye with a water source and nutrients or different chemicals. This mixture aims to match the wastewater characteristics with those of real effluents containing various chemicals, auxiliaries and dyestuffs added during textile manufacturing steps. Synthetic wastewaters prepared by various researchers are summarised in Table 5. These synthetic effluents, which have been treated by different chemical, physical and biological methods, consist of some common chemicals corresponding to their occurrence in specific steps in the textile manufacturing processes. The following sections highlight the known reported constituents for preparing synthetic textile wastewater according to the specified methods of treatment.

Reported constituents of synthetic textile wastewater treated by biological methods

Constituents treated by wetland systems

Mbuligwe (2005) investigated the potential of two types of aquatic plants using engineered wetland systems for treatment of synthetic effluents. The dye-rich artificial wastewater was prepared by mixing caustic soda, sodium hydrosulphate and dye powder with tap water. The planted wetland outperformed the unplanted one in colour and COD removal. In addition, the potential of Araceae (aroid family) for the uptake of dyes was higher than for *Typha* spp. L. (bulrush in the UK and cattail in the USA), which reflect differences between the plants' treatment capacity (e.g. adsorbent sites are dissimilar) during the adsorption process.

Keskinkan and Göksu (2007) treated synthetic wastewater contaminated with basic blue 41. The mixture contained 11 mg/l of the dye with 5% Arnon-Hoagland nutrients, which included chemicals such as potassium nitrate, calcium nitrate, ammonium dihydrogen phosphate, magnesium sulphate heptahydrate, boric acid, manganese(II) chloride

Table 5 Reported chemical constituents used for preparation of synthetic textile wastewater containing dyes

References	Dhaouefi et al. (2018)		Yaseen and Scholz (2018)[a]		Hussein and Scholz (2017)	
Country	Spain		UK		UK	
Method	anoxic-aerobic photo-bioreactor		Wetland (microcosms) with free floating plants		Vertical-flow constructed wetland with emergent plants	
COTOBLANC KRS	330 mg/l	Sodium acetate	204.9 mg/l		TNC Complete fertiliser	0.1 ml/l
BIAVIN BPA	330 mg/l	Ammonium nitrate	176.1 mg/l		Acid Blue 113, Basic Red 46	7215 mg/l
MEROPAN DA	170 mg/l	Sodium chloride	7 mg/l			
Trisodium phosphate	330 mg/l	Magnesium chloride hexahydrate	3.4 mg/l			
Sodium hydroxide	1000 mg/l	Calcium chloride dihydrate	4 mg/l			
Sodium hydrosulphate	900 mg/l	Potassium Hydrogen Phosphate Trihydrate	36.7 mg/l			
Acetic acid	170 mg/l	Sodium benzoate	107.1 mg/l			
Ammonium sulphate	600 mg/l	Basic Red 46 and Reactive Blue 198	10 mg/l			
Disperse blue 1	12 mg/l					
Disperse orange 3	20 mg/l					

References	Yaseen and Scholz (2016, 2017a, b)	Mountassir et al. (2015)		Punzi et al. (2015)	
Country	UK	Morocco		India	
Method	Wetland pond with free floating plants	Electrocoagulation		Anaerobic biofilm reactors	
TNC Complete fertiliser	0.1 ml/l	Starch	2.78 mg/l	Starch	0.465 g/l
Acid blue 113, Basic Red 46; Reactive Blue 198 and Direct Orange 46	5 mg/l	Ammonium sulphate	5.56 mg/l	Sodium chloride	10 g/l
		Disodium phosphate	5.56 mg/l	Remazol Red	10 g/l
		Reactive Violet 4	0.8 absorbance unit		

References	Verma et al. (2012, 2015)	Al-Amrani et al. (2014)		Aldoury et al. (2014)	
Country	India				
Method	Coagulation method	Sequential batch reactors		Sequential anaerobic/aerobic	
Starch	1000 mg/l	Sucrose	563 mg/l	Dipotassium hydrogen phosphate	15 mg/l
Acetic acid	200 mg/l	Bacto-peptone	188 mg/l	Calcium chloride	20 mg/l
Sucrose	600 mg/l	Iron (III) Chloride Hexahydrate	11.3 mg/l	Magnesium sulphate heptahydrate	20 mg/l
Sodium hydroxide	500 mg/l	Calcium chloride	40 mg/l	Zinc sulphate	1 mg/l
Sulphuric acid	300 mg/l	Magnesium sulphate	49 mg/l	Iron(III) chloride	2 mg/l
Sodium carbonate	500 mg/l	Sodium bicarbonate	100 mg/l	Sodium bicarbonate	50 mg/l
Sodium chloride	3000 mg/l	Ammonium chloride	172 mg/l	Ammonium chloride	10 mg/l
Sodium lauryl sulphate	100 mg/l	Potassium dihydrogen phosphate	513 mg/l	Peptone	50 mg/l
Reactive Black 5, Congo Red and Disperse Blue 3	200 mg/l	Acid Orange 7, Acid Orange 10, Acid Yellow 9 and Acid Red 14	30, 75 and 150 mg/l	Acid Orange 12, Disperse Red 17	100, 150 and 200 mg/l

Table 5 (continued)

References	Aouni et al. (2012)	Cumnan and Yimrattanabovorn (2012)		Nopkhuntod et al. (2012)	
Country	Spain	Thailand		Thailand	
Method	Ultrafiltration and nanofiltration processes	Constructed wetlands with emergent plants		Adsorption by shale column	
Sodium chloride	500 mg/l	Benzoic acid sodium salt	53.55 mg/l	Sodium chloride	40 g/l
Everzol Black, Everzol Blue and Everzol Red	60 mg/l	Acetic acid sodium salt	204.9 mg/l	Sodium hydroxide	1.5 g/l
		Ammonium nitrate	176.1 mg/l	Sodium carbonate	2 g/l
		Sodium chloride	7 mg/l	Reactive dye	0.6 g/l
		Magnesium chloride hexahydrate	3.4 mg/l		
		Calcium chloride dihydrate	4 mg/l		
		Potassium Hydrogen Phosphate Trihydrate	36.7 mg/l		
		Dye	11.5 mg/l		

References	Noonpui and Thiravetyan (2011)[b] and Sakkayawong et al. ((2005))	Muda et al. (2010)		Ong et al. (2009, 2010)	
Country	Thailand			Japan	
Method	Constructed wetland with emergent plants; adsorption by chitosan	Sequential batch reactors using granular sludge		Up-flow constructed wetland with emergent plants	
Sodium carbonate	90 g/l	Glucose	0.5 g/l	Sodium benzoate	107.1 mg/l
Sodium sulphate	20 g/l	Ethanol	0.125 g/l	Sodium acetate	204.9 mg/l
Reactive red 141	4 g/l	Sodium acetate	0.5 g/l	Ammonium nitrate	176.1 mg/l
		Ammonium chloride	0.16 g/l	Sodium chloride	7 mg/l
		Potassium dihydrogen phosphate	0.23 g/l	Magnesium chloride hexahydrate	3.4 mg/l
		Dipotassium phosphate	0.58 g/l	Calcium chloride dihydrate	4 mg/l
		Calcium chloride dihydrate	0.07 g/l	Potassium Hydrogen Phosphate Trihydrate	36.7 mg/l
		Magnesium sulphate heptahydrate	0.09 g/l	Acid Orange 7	50, 100 mg/l
		Ethylenediaminetetraacetic acid	0.02 g/l		
		Boric acid[c]	0.15 g/l		
		Ferrous chloride[c]	1.5 g/l		
		Zinc chloride[c]	0.12 g/l		
		Manganese(II) chloride tetrahydrate[c]	0.12 g/l		
		Copper(II) chloride dihydrate[c]	0.03 g/l		
		Sodium molybdate[c]	0.06 g/l		
		Cobalt(II) chloride hexahydrate[c]	0.15 g/l		
		Potassium iodide[c]	0.03 g/l		
		Sumifix Black EXA, Sumifix Navy Blue EXF and Synozol Red K-4B	50 mg/l		

Table 5 (continued)

References	Avlonitis et al. (2008)			Hassani et al. (2008)		Bulc and Ojstršek (2008)			
Country	Austria			Iran		Austria			
Method	Nanofiltration processes					Constructed wetland with emergent plants			
Sodium carbonate	40 mg/l	80 mg/l	100 mg/l	Sodium chloride	1000, 2000, 3000 mg/l TDS	Alvirol AGK	0.3 g/l	0.3 g/l	0.3 g/l
Sodium hydroxide	20 mg/l	40 mg/l	50 mg/l	Cyanine 5R, Red E3B, Direct red 105 and Carmozin 206	5, 50, 100 mg/l	Cibaflow PAD	0.3 g/l	0.3 g/l	0.3 g/l
Sodium chloride	600 mg/l	1200 mg/l	1500 mg/l						
Reactive Black 5	130 mg/l	260 mg/l	230 mg/l			Sodium chloride			
						Sodium hydroxide	2 ml/l		

References	Bali and Karagozoglu (2007)			Keskinkan and Göksu (2007)[e]		Ojstršek et al. (2007)			
Country	Turkey			Turkey		Austria			
Method	Fenton process			Constructed wetland with submerged plants		Constructed wetland with emergent plants			
Polyvinyl alcohol		100 mg/l		Potassium nitrate	1020 mg/l	Alvirol AGK	0.46 g/l	0.3 g/l	0.3 g/l
Remazol Turquoise Blue G-133		50 mg/l		Calcium nitrate	492 mg/l	Alviron VKSB	0.67 g/l	0.4 g/l	
				Ammonium dihydrogen phosphate	230 mg/l	Sodium chloride	2 g/l	2 g/l	
				Magnesium sulphate heptahydrate	420 mg/l	Sodium hydroxide	2 ml/l	2 ml/l	
Irgapadol MP		2 g/l	2 g/l	Boric acid	2.86 mg/l	Irgapadol MP			1.67 g/l
Reactive Black 5	0.03 g/l			Manganese(II) chloride tetrahydrate	1.81 mg/l	Cibaflow PAD			0.3 g/l
Disperse Yellow 211		0.03 g/l		Molybdenum (VI) acid monohydrate	0.09 mg/l	Reactive Red 22	0.03 g/l		
Vat Yellow 46			0.03 g/l	Iron(II) sulphate heptahydrate	0.07 mg/l	Reactive Black 5		0.03 g/l	
				$(CHOH)_2(COOH)_2$	0.02 mg/l	Vat Red 13			0.03 g/l
				Basic Blue 41	11 mg/l				

References	Khehra et al. (2006)		Mbuligwe (2005)		Mbuligwe (2005)	
Country	India		Tanzania			
Method	Sequential anoxic/aerobic bioreactor		Engineering wetland with emergent plants		Advanced oxidation	
Disodium phosphate	3.6 g/l		Caustic soda	0.2 g/l	Acetic acid	0.79 g/l
Ammonium sulphate	1 g/l		Sodium hydrosulphate	0.3 g/l	Sodium chloride	41 g/l
Potassium dihydrogen phosphate	1 g/l		Dye	0.2 g/l	Sodium carbonate	13 g/l
Magnesium sulphate heptahydrate	1 g/l				Sodium hydroxide	0.51 g/l
Fe (NH_4) citrate	0.01 g/l				Polyether based co-polymer micro-dispersion	1.2 g/l
Calcium chloride dihydrate	0.1 g/l				Acryl co-polymer-phosphor mixture	0.85 g/l
Yeast extract	0.05% (w/v)				Alkyl phenol polyglycol ether	0.5 g/l
Glucose	2.8 mM				Procion blue HERD	6.83 mg/l
Zinc sulphate heptahydrate[c]	10 mg/l				Procion crimson HEXL	40.6 mg/l

Table 5 (continued)

References	Khehra et al. (2006)	Mbuligwe (2005)	Mbuligwe (2005)
Country	India	Tanzania	
Method	Sequential anoxic/aerobic bioreactor	Engineering wetland with emergent plants	Advanced oxidation
Manganese(II) chloride tetrahydrate[c]	3 mg/l		Procion Yellow HE4R 15 mg/l
Cobalt(II) chloride hexahydrate[c]	1 mg/l		Procion navy HEXL 86.3 mg/l
Nickel(II) chloride hexahydrate[c]	2 mg/l		Procion yellow HEXL 33.3 mg/l
Sodium molybdate dihydrate[c]	3 mg/l		
Boric acid[c]	30 mg/l		
Copper(II) chloride dihydrate[c]	1 mg/l		
Acid Red 88	100 mg/l		

References	Kang et al. (2002)	Mohan et al. (2002)	Panswad et al. (2001)
Country	Taiwan	India	Thailand
Method	Fenton process	Biological treatment by algae	Anaerobic/aerobic sequential batch reactor
Polyvinyl alcohol	125 mg/l	D-glucose 0.1 g/l	Nutrient broth (f) 500, 350, 250 mg/l
Reactive Blue dye R94H	20 mg/l	Sodium chloride 0.05 g/l	Sodium acetate (f) 150, 250, 500 mg/l
		$FeCl_3 \cdot H_2O$[c] 7100 mg/l	Glucose (f) 500 mg/l
		Zinc sulphate heptahydrate[c] 1 mg/l	Urea 50, 25 mg/l (as N)
		Magnesium sulphate heptahydrate[c] 5000 mg/l	Potassium dihydrogen phosphate 15, 5 mg/l (as P)
		Boric acid[c] 1 mg/l	Sodium bicarbonate 500 mg/l (as CaCO)
		Copper (II) sulphate pentahydrate[c] Manganese(II) Chloride Dihydrate[b] 1 mg/l	Iron (III) Chloride Hexahydrate 2.5 mg/l (as Fe)
		Ammonium Molybdate[c] 1.1 mg/l	Magnesium sulphate heptahydrate 3.75, 1.25 mg/l (as Mg)
		Manganese(II) Chloride Dihydrate[c] 80 mg/l	Calcium chloride 7.5, 2.5 mg/l (as Ca)
		Aluminium sulphate hexadecahydrate[c] 550 mg/l	Remazol black B 10 mg/l
		Calcium chloride dihydrate[c] 10,000 mg/l	
		Cobalt(II) chloride hexahydrate[c] 2000 mg/l	
		Thiamine–HCl hydrogen chloride[c] 2000 mg/l	
		Reactive Yellow 22 0.25, 0.5 and 1.0 g/l	

References	Panswad and Luangdilok (2000)	Basibuyuk and Forster (1997)	Marquez and Costa (1996)
Country		UK	Spain
Method	Anaerobic/aerobic sequential batch reactor	Sequential biofilter using activated sludge	Adsorption by powdered activated carbon and activated sludge
Glucose	860 mg/l	Starch 1.28 g/l	Meat extract 110 mg/l

Table 5 (continued)

References	Panswad and Luangdilok (2000)	Basibuyuk and Forster (1997)		Marquez and Costa (1996)	
Country		UK		Spain	
Method	Anaerobic/aerobic sequential batch reactor	Sequential biofilter using activated sludge		Adsorption by powdered activated carbon and activated sludge	
Acetic acid	0.150 mg/l	Lab Lemco	400 mg/l	Urea	30 mg/l
Urea	108 mg/l	Ammonium sulphate	353 mg/l	Dipotassium hydrogen phosphate	28 mg/l
Potassium dihydrogen phosphate	67 mg/l	Magnesium sulphate heptahydrate	108 mg/l	Sodium chloride	7 mg/l
Sodium bicarbonate	840 mg/l	Calcium chloride	40 mg/l	Calcium chloride dihydrate	4 mg/l
Magnesium sulphate heptahydrate	38 mg/l	Iron(II) sulphate heptahydrate	750 µg/l	Magnesium sulphate heptahydrate	2 mg/l
Calcium chloride	21 mg/l	Nickel(II) sulphate heptahydrate	500 µg/l	Acid Orange 7	20 mg/l
Iron (III) chloride hexahydrate	7 mg/l	Manganese(II) chloride tetrahydrate	500 µg/l		
Reactive Black 5, Reactive Blue 19, Reactive Blue 5 and Reactive Blue 198	20 mg/l	Zinc sulphate heptahydrate	500 µg/l		
		Boric acid	100 µg/l		
		Cobalt(II) chloride hexahydrate	50 µg/l		
		Copper(II) sulphate pentahydrate	5 µg/l		
		Maxilon Red	25–50 mg/l		

[a]The constituents mixture, except the dyes, diluted by 1 part of mixture to 24 part of raw water, [b]this ingredient originates from a stock solution and further dilution was applied to obtain a 20 mg/l dye concentration, [c] composition of trace element solution using 1 ml/l except Khehra et al. 2006 used 10 ml/l, [d]the authors mixed each dye separately at three concentrations with sodium chloride, which provided three concentrations of total dissolved solids (TDS), [e]5% of the chemical solution mixed with the dye, [f]the chemicals mixed with either NB and SA or with glucose providing 500 mg/l as COD

tetrahydrate, molybdenum (VI) acid monohydrate and iron(II) sulphate heptahydrate. The treatment was carried out using wetland technology vegetated by submerged plants and results showed high dye removal efficiencies of more than 90%, using both *Myriophyllum spicatum* L. (Eurasian watermilfoil) and *Ceratophyllum demersum* L. (hornwort).

Ojstršek et al. (2007) operated two CW systems: one consisting of four substrate layers (gravel, sand, zeolite and peat) and another one without peat for the treatment of three dye bath wastewaters. These baths contained the dyes reactive red 22 (RR22), RB5 and vat red 13 (VR13) (one for each bath) mixed with sodium hydroxide, sodium chloride and auxiliaries (irgapadol MP, alvirol AGK, cibaflow PAD and alviron VKSB) to simulate dye-rich textile wastewater. The dye baths were prepared by dissolving the dye and the auxiliaries with tap and distilled water. This study achieved dye removal efficiencies of around 40%, 70% and 43% for RR22, RB5, VR13, respectively, for wetlands without peat, which showed high COD and TOC reductions compared with the wetlands containing peat. Dye reduction was due to filtration and/or adsorption processes. Bulc and Ojstršek (2008) investigated the ability of the same system with gravel, sand and zeolite substrate layers using the same chemicals and auxiliaries except for alviron VKSB. The dyes used in each bath were RB5, disperse yellow 211 and vat yellow 46. This study indicates dye removal efficiencies of around 70% by filtration and adsorption processes. However, the system was able to remove around 45% of both COD and TOC.

Ong et al. (2009, 2010) studied the ability of an up-flow CW for treatment of artificial textile wastewater comprising 50 and 100 mg/l of the azo dye AO7. The synthetic textile wastewater consisted of ammonium nitrate, magnesium chloride hexahydrate, calcium chloride dihydrate, sodium benzoate, sodium acetate, potassium phosphate and sodium chloride. The aerated reactor outperformed the non-aerated one regarding the removal of AO7, nutrients and other pollutants. This is because the supplementary aeration option controlled aerobic and anaerobic environments in the wetland systems by providing both these conditions within the upper and lower media beds, respectively, of treatment system compared with the non-aerated reactors, which provide only an anaerobic condition within the whole bed of the

wetland system. In addition, results showed that the increase of dye concentration reduced the organic matter and nitrification process in the non-aerated reactor as well as the denitrification and dye removal in the aerated reactor.

Noonpui and Thiravetyan (2011) examined the potential of *Echinodorus* spp. in CW with and without soil for removal of RR141 at a concentration of 20 mg/l. The synthetic reactive red 141 wastewaters contained a mixture of the dye RR141, sodium carbonate and sodium sulphate, which was prepared according to the dyeing procedures in the textile factory. Results showed that the presence of soil within a wetland does not greatly affect dye removal. However, the outflow values of pH, total dissolved solids (TDS) and electric conductivity are greatly impacted on by soil-based wetland systems, as these values were lower in wetlands without soil compared to the wetlands containing soil substrate.

Cumnan and Yimrattanabovorn (2012) evaluated the efficiency of integrated free water surface and subsurface flow CW planted with *P. australis* for the treatment of azo dye in artificial textile wastewater using the same constituents as those reported by Ong et al. (2009). However, the authors reduced the concentration of the sodium benzoate by half, and the dye to 11.5 mg/l. This study concluded that the integrated system improved the water quality parameters significantly ($p < 0.05$) due to the presence of both anaerobic and aerobic conditions within the integrated system. This is because organic matter degradation (e.g. COD) by microbial activity requires aerobic conditions, and colour removal by bacteria is enhanced within the anaerobic zones. Results also showed that the presence of plants increased the colour removal, as the plants have the ability to adsorb dyes.

Yaseen and Scholz (2016, 2017a, b) operated a wetland pond system for the treatment of artificial wastewater. The mixture contained fertiliser mixed with tap water and four textile dyes (AB113, basic red 46 (BR46), reactive blue 198 (RB198), and direct orange 46) at a concentration of 5 mg/l. The fertiliser comprised of nitrogen (1.5%), phosphorus (0.2%), potassium (5%), magnesium (0.8%), iron (0.08%), manganese (0.018%), copper (0.002%), zinc (0.01%), boron (0.01%), molybdenum (0.001%) and ethylenediaminetetraacetic acid. The pond experiment was efficient in significantly ($p < 0.05$) removing the dye BR46, by adsorption processes, due to the simple structure and low molecular weight of this dye. However, Hussein and Scholz (2017) operated a vertical-flow CW for the treatment of the same artificial effluents mixed with the dye AB113 and BR46 at high (215 mg/l) and low (7 mg/l) concentrations for preparing four influent paths. Results showed that the wetland was able to remove the dyes BR46 and AB113. The removal efficiencies ranged between 79 and 96%, and 94 and 82% for BR46 at low and high concentrations, respectively, and between 68 and 80%, and 71 and 73%, for the dye AB113 at low and high concentrations, respectively.

Yaseen and Scholz (2018) operated simulated pond systems (microcosms) for the treatment of artificial textile wastewater. The treatment system was vegetated by *Lemna minor* L. The inflow mixture contained the constituents used by Ong et al. (2010). However, the inflow was diluted: 1 part of synthetic textile wastewater to 24 parts of raw water to ensure that the plants used in the system survive. The diluted constituents were mixed with three mixtures of the dyes BR46 and RB198 at different percentages of the total concentration of 10 mg/l. Results showed that the removal efficiencies were higher for the mixture containing high percentages of biodegradable dye (BR46), and the main mechanisms of dye elimination by plants were both phytotransformation and adsorption processes.

Constituents treated by other biological systems

Basibuyuk and Forster (1997) operated four up-flow aerated biofilters in sequence for treatment of simulated textile wastewater using activated sludge. The artificial textile wastewater contained the dye maxilon red at two concentrations (25 mg/l and 50 mg/l), starch, lab lemco, diammonium phosphate, magnesium sulphate heptahydrate, calcium chloride, iron(II) sulphate heptahydrate, nickel(II) sulphate heptahydrate, manganese(II) chloride tetrahydrate, zinc sulphate heptahydrate, boric acid, cobalt(II) chloride hexahydrate and copper(II) sulphate pentahydrate. The studied reactor achieved high colour removal efficiency (99%) due to the sludge capability to adsorb the dye onto their adsorbent sites.

The treatment of synthetic wastewater contaminated with textile dyes was evaluated by Panswad and Luangdilok (2000). They investigated the efficiency of an anaerobic/aerobic sequential batch reactor system for treatment of simulated dye wastewater containing 20 mg/l of four dyes (RB5, reactive blue 19, reactive blue 5, and RB198) mixed with glucose, acetic acid, urea, potassium dihydrogen phosphate, sodium hydrogen carbonate, magnesium sulphate heptahydrate, calcium chloride and iron(III) chloride hexahydrate. Colour removal was relatively higher within the anaerobic phase compared to the aerobic one for the first three dyes only. The decolourisation of the dye RB5 was by reductive reaction, which resulted in the cleavage of the azo bond. However, the decolorisation of reactive blue 19 and reactive blue 5 dyes was due to the adsorption of dyes on bacterial floc materials.

Panswad et al. (2001) evaluated the treatment of synthetic wastewater contaminated with remazol black B using an anaerobic/aerobic sequential batch reactor with sludge. The wastewater consisted of nutrient broth, sodium acetate, glucose, urea, potassium dihydrogen phosphate, sodium bicarbonate, iron (III) chloride hexahydrate, magnesium sulphate

heptahydrate and calcium chloride. The authors mixed all chemicals with nutrient broth and sodium acetate in different concentrations, providing in total around 500 mg/l COD for polyphosphate-accumulating organisms on the one hand and glycogen-accumulating organisms on the other hand. Results showed that colour removal efficiency within the anaerobic phase (71.5%) was higher compared to the aerobic phase (1.6%), indicating that the anaerobic stage is very important for a good biological decolourisation, which occurred due to the cleavage of the azo bond.

Mohan et al. (2002) used *Spirogyra* spp. (O. F. Müller) Dumortier (water silk) for the treatment of artificial effluents containing the azo dye reactive yellow 22 (RY 22). The simulated wastewater was prepared by mixing a proportion of the stock solution for RY 22 with D-glucose, sodium chloride and 1 ml/l trace element solution with distilled water. Tap water was used for further dilutions. The trace element solution consisted of different chemicals. The batch experiment indicated that the maximum colour removal was reached on the third day and depended on the dye concentration and the biomass of the algae.

Khehra et al. (2006) operated a sequential anoxic/aerobic bioreactor for the treatment of simulated wastewater containing the dye acid red 88. The artificial wastewater consisted of 100 mg/l of the dye mixed with yeast extract, glucose and mineral salts. The mineral salt medium consisted of disodium phosphate, ammonium sulphate, potassium dihydrogen phosphate, magnesium sulphate heptahydrate, ammonium ferric citrate, calcium chloride dihydrate and trace elements. The trace element solution comprised of zinc sulphate heptahydrate, manganese(II) chloride tetrahydrate, cobalt(II) chloride hexahydrate, nickel(II) chloride hexahydrate, sodium molybdate dihydrate, boric acid and copper(II) chloride dihydrate. The system was highly efficient, achieving removal of the dye and COD of around 98% and 95%, respectively. This is because the biological composition within the treatment system is active under both anoxic and aerobic conditions, leading to a complete degradation of the dye structure by biotransformation processes.

Muda et al. (2010) used granular sludge in a single sequential batch reactor with anaerobic and aerobic conditions for treatment of simulated textile effluents. The artificial wastewater consisted of glucose, ethanol, sodium acetate, ammonium chloride, potassium dihydrogen phosphate, dipotassium phosphate, calcium chloride dihydrate, magnesium sulphate heptahydrate, ethylenediaminetetraacetic acid, dye mixture (sumifix black EXA, sumifix navy blue EXF and synozol red K-4B) and 1 ml/l of trace element solution. The composition of the trace elements solution, as reported by Smolders et al. (1995), included among other ingredients boric acid, zinc chloride ($ZnCl_2$), manganese(II) chloride tetrahydrate, copper(II) chloride dihydrate, sodium molybdate, cobalt(II) chloride hexahydrate and potassium iodide. The COD and ammonium reductions were more than 90%, which was due to the occurrence of high biological activity within the system. However, the colour removal efficiency was only 62% due to the insufficient adaptation time for dye removal, as mentioned above. This is because the recalcitrant (difficult to degraded) nature of the dye required more time to accumulate enough organisms for achieving dye degradation in the treatment system.

Aldoury et al. (2014) studied the ability of sequential anaerobic/aerobic reactors for treatment of synthetic wastewater contaminated with two dyes (acid orange 12 and disperse red 17). The wastewater was prepared by mixing potassium hydrogen phosphate, calcium chloride, magnesium sulphate heptahydrate, zinc sulphate, iron(III) chloride, sodium bicarbonate, ammonium chloride, peptone, dyes and tap water. Higher COD removal was achieved using the aerobic reactor, and higher dye removal was found using the anaerobic reactor for both dyes.

Al-Amrani et al. (2014) examined the performance of an anoxic/aerobic REACT sequential batch reactor system for COD and azo dyes (AO7, acid orange 10, acid yellow 9 and acid red 14) removals by preparing synthetic textile wastewater. The wastewater constituents included the dye mixed with sucrose, bacto-peptone, iron (III) chloride hexahydrate, calcium chloride, magnesium sulphate, sodium hydrogen carbonate, ammonium chloride and potassium dihydrogen phosphate. Results showed that the system is suitable for textile wastewater treatment, and a higher reduction efficiency of dyes and COD can be achieved within the system without co-substrate.

Dhaouefi et al. (2018) examined the suitability of using an anoxic/aerobic photobioreactor for carbon and nutrient removal from synthetic textile wastewater. The mixture of synthetic wastewater contained soaping agent, anticrease, dispersing agent, electrolyte, alkaline agent, reducing agent, acid generation, as well as the dyes disperse blue 1 and disperse orange 3. Results showed that the microalgae bacteria supported the removal efficiencies of total organic carbon (48%), total nitrogen (87%) total phosphorus (57%), dye disperse orange 3 (80%), and disperse blue 1 (75%) at a contact time of 10 days.

Reported constituents of synthetic textile wastewater treated by chemical methods

Alaton et al. (2002) focused on studying the efficiency of different advanced oxidation processes (O_3/OH^-, H_2O_2/UV-C and TiO_2/UV-A) for treatment of simulated wastewater comprising a mixture of five reactive dyes and different auxiliaries in concentrations, which matched those of the reactive dye effluents discharged from a cotton factory. The chemicals used in the mixture were acetic acid,

sodium chloride, sodium carbonate, sodium hydroxide, polyether based co-polymer micro-dispersion, acryl co-polymer-phosphor mixture and alkylphenol polyglycol ether. The mixture of the dyes and auxiliaries was first dissolved in boiling deionised water to ensure that all the chemicals hydrolysed, and then stored for 12 h in a cool room before use. Results showed that O_3/OH^- and H_2O_2/UV-C oxidation appear to be promising candidates for full-scale textile dye effluent removal.

Kang et al. (2002) studied the Fenton process (involving oxidation and coagulation) for the treatment of synthetic textile wastewater containing polyvinyl alcohol mixed with reactive blue dye R94H to simulate COD and colour, respectively. The treatment results showed that the colour removal of around 95% was achieved in 5 min by the Fenton process, which occurs mainly in the first stage of the hydroxyl radical oxidation, and the subsequent ferric coagulation plays only a minor role. In addition, outcomes showed that considerable dosages of Fenton reagent are required to achieve an acceptable efficiency for COD removal.

Sakkayawong et al. (2005) focused on chemical adsorption by chitosan for the treatment of synthetic wastewaters containing a mixture of the dye reactive red 141 at a concentration of 400 mg/l, sodium carbonate and sodium sulphate, which was prepared according to the dye procedures in the textile factory. Results showed that chitosan, as an adsorbent, is able to remove the reactive dyes from textile wastewater because it can adsorb these dyes over a wide pH range and at high temperatures.

Bali and Karagozoglu (2007) studied the Fenton process (involving oxidation and coagulation), ferric coagulation and the H_2O_2/pyridine/Cu(II) system for the removal of colour from a synthetic textile wastewater containing polyvinyl alcohol and a reactive dye (remazol turquoise blue G-133). A colour removal efficiency of around 95% was achieved with Fenton's reagent at an optimum [Fe(II)]:[H_2O_2] molar ratio of 1.21:1, and a colour removal of 92% was noted for the H_2O_2/pyridine/Cu(II) system.

Verma et al. (2012) studied the effectiveness of magnesium chloride and ferrous sulphate as chemical coagulant materials with lime as a coagulant aid for treating artificial textile wastewater. They introduced constituents for a synthetic textile wastewater to simulate the characteristics of the real textile effluents in Tirupur (India) reported on by Eswaramoorthi et al. (2008). The composition consisted of starch, acetic acid, sucrose, sodium hydroxide, sulphuric acid, sodium carbonate, sodium chloride, sodium lauryl sulphate and dye, which were mixed using tap water. The dyes used were RB 5, congo red and disperse blue 3 at total concentrations of 200 mg/l. This study concluded that magnesium chloride outperformed ferrous sulphate, and the presence of lime with magnesium chloride improved dye and COD reductions more than other coagulants. Later, Verma et al. (2015) used an anaerobic sludge blanket reactor as a pre-treatment step of the same synthetic textile wastewater using a magnesium chloride and aluminium chlorohydrate mixture. Around 98% and more than 99% reduction rates were achieved in this work for COD and colour, respectively.

Mountassir et al. (2015) treated synthetic textile effluents by an electrocoagulation method with an aluminium electrode in the presence of clay particles. The wastewater was prepared by mixing the dye reactive violet 4, starch, ammonium sulphate and disodium phosphate in deionised water. The removal efficiency of colour and COD increased remarkably in the presence of clay particles, making this approach very successful compared with conventional methods.

Punzi et al. (2015) proposed a novel method for treating artificial textile effluents using an anaerobic biofilm reactor followed by ozonation. The synthetic effluent contained starch dissolved in heated water and mixed with sodium hydroxide, sodium chloride and the azo dye remazol red (RR). This study concluded that ozonation as a post-treatment after an anaerobic biological treatment process was a promising technique for high COD, colour and toxicity removal.

Reported constituents of synthetic textile wastewater treated by physical methods

Marquez and Costa (1996) prepared artificial textile effluent for evaluation by the powdered activated carbon treatment process. Artificial wastewater was matched to the effluent from textile dyeing wastewater. The mixture contained peptone, meat extract, urea, potassium hydrogen phosphate, sodium chloride, calcium chloride dihydrate, magnesium sulphate heptahydrate and the dye AO7. The authors operated the system after batch testing for detection of the optimum adsorption conditions, and they concluded that the biomass contributed very effectively to the dye removal.

Avlonitis et al. (2008) examined the impact of various operational conditions concerning the performance of a nanofiltration membrane technique for treatment of three synthetic textile dyeing wastewaters. The synthetic wastewaters were prepared by dissolving salts and the dye RB 5 using tap water at concentrations higher than the typical ranges found in the effluents of the cotton dye industry. The treated effluents were useful for recycling and reuse purposes due to the system abilities for complete decolourisation and salt reduction. Hassani et al. (2008) studied the impact of different TDS values (1000, 2000 and 3000 mg/l) on dye removal efficiency by mixing the dyes with sodium chloride using the nanofiltration technique.

Aouni et al. (2012) evaluated ultrafiltration and nanofiltration techniques for the treatment of synthetic dye wastewater

in Spain. The artificial reactive dye wastewater was prepared by mixing 15 g from each dye separately (everzol black, everzol blue and everzol red) with 2 l ultra-pure water. This was followed by mixing with 12.5 g sodium chloride and ultra-pure water to prepare 25 l of dye solution in total. Sodium hydroxide was added for pH adjustment to reach a pH value of 10. The dye concentration was 600 mg/l. Results showed that the nanofiltration process was more efficient than ultrafiltration for COD, colour and conductivity reduction.

Nopkhuntod et al. (2012) conducted a batch test using shale as an adsorbent material before the main experiment to examine the operational parameters for removing the dyes reactive red, blue and yellow separately by preparing synthetic dye wastewater. The synthetic effluents contained reactive dye and sodium chloride in a specific concentration dissolved with distilled water. The mixture was heated to 60 °C for 2 h and sodium carbonate was added within the first hour. Thereafter, sodium hydroxide was added for preparing 1 l of wastewater solution. The findings indicated that the shale was very effective and the optimum conditions for maximum adsorption were reached at a temperature of 45 °C, an initial pH of 2 and an initial concentration of 700 Pt–Co.

Chemicals used for textile wastewater simulation

Artificial textile or dyeing wastewater was prepared by mixing different chemicals in specific proportions to simulate the wide variety of textile effluents. The components of these constituents and their concentrations are summarised in Table 5, and the corresponding water quality characteristics are shown in Table 6. The most common chemicals reported for synthetic textile wastewater preparation correspond to particular steps in the textile manufacturing processes (Fig. 1).

The sizing process is the first step for preparation of the fabric and involves adding sizing agents such as starch, polyvinyl alcohol and carboxymethyl cellulose (Liu et al. 2010) to make the fibre stronger and reduce ruptures. However, these agents hinder other processes such as dyeing, printing and finishing. For example, starch impedes dye penetration into the fibre. Therefore, de-sizing is required as a second step for eliminating all materials added during the sizing step by applying hydrolysis or an oxidation agent (Babu et al. 2007) such as enzymes, sodium bromide, sodium chloride and hydrogen peroxide.

The scouring step is the process of adding alkali solution such as sodium hydroxide, potassium hydroxide or sodium carbonate to remove oils and waxes, and suspend contamination from fibres. After that, the bleaching process is used for removing the undesirable colour or creamy appearance, improving the whiteness and brightness of the fibres by adding bleaching chemicals such as hydrogen peroxide, sodium hypochlorite, hypochlorite and peracetic acid (Babu et al. 2007).

The mercerising process follows, increasing the fibre appearance, strength and the dye uptake by adding concentrated sodium hydroxide and acid solutions. The application of neutralisation agents including acetic acid or formic acid is required to neutralise the fibres after the scouring, bleaching, reduction and mercerising processes. Bradbury et al. (2000) suggested the use of formic acid as an efficient, cheap and ecological compound providing an adequate degree of neutralisation and achieving a low BOD value using a limited quantity of water.

Regarding the dyeing and printing processes, dyeing is the application of colour as a solution to fibres, whereas printing is undertaken by adding the colour as a thick paste. To improve the binding between dyes and fabric, different chemicals have been added such as metals, salts, surfactants, organic processing aids, sulphide and formaldehyde. The main dye types used in textile factories are direct, basic, disperse, reactive, pigment and vat. The final part of the textile process is the finishing step where fabric softening, cross-linking and waterproofing is achieved by adding formaldehyde-based agents (Babu et al. 2007).

Starch, glucose, nutrient broth, sodium acetate or acetic acid can be used as a source for carbon in preparing the various synthetic textile wastewaters as mentioned in Table 5. Verma et al. (2012, 2015) described using starch, sucrose and acetic acid as sizing agents. However, Alaton et al. (2002) used acetic acid as a neutralisation agent.

Salts within textile constituents can be presented as different sources such as sodium chloride, sodium carbonate, sodium hydrogen carbonate and sodium phosphate. These chemicals are used in dyeing and printing processes in textile factories as the main compound for enhancing the fixation between dyestuffs and fabrics (Aouni et al. 2012). Sodium chloride is widely used by researchers to resemble the textile effluents as reported in Table 5. Bes-Piá et al. (2010) mentioned that the chlorides in the salts are the main sources responsible for increasing the conductivity of the wastewater.

Sodium carbonate (soda ash) is used as a fixing agent in textile factories and as a buffer solution for pH. Sodium sulphate (soda) is an inorganic compound used to prepare the synthetic dye wastewater; it is also used with sodium carbonate as an indicator for TDS and conductivity monitoring in treatment systems (Noonpui and Thiravetyan 2011). Calcium nitrate and calcium chloride are inorganic salts that are extensively used as the main source for calcium ions in the artificial wastewater. Sodium hydroxide is an inorganic chemical, also known as caustic soda, used

Table 6 Characteristics of the reported chemical constituents in Table 5

Parameter	pH (–)	COD (mg/l)	COD/BOD (–)	DO (mg/l)	EC (µS/cm)	TDS (mg/l)	SS (mg/l)	Turbidity (NTU)	Chloride (mg/l)
Yaseen and Scholz (2018)	7.3 m1 7.2 m2 7.2 m3	33.7 29.2 31.8		8.9 8.8 8.9	109.9 112.4 112.1	55.0 56.2 56.1	2.3 3.0 2.8	2.4 3.1 3.0	
Hussein and Scholz (2017)	7.2 ± 0.15[a] 6.5 ± 0.18[b] 7.3 ± 0.12[c] 8.4 ± 0.4[d]	22 ± 6 261 ± 11 48.2 ± 12.2 584 ± 34		9.7 ± 0.5 9.6 ± 0.4 9.6 ± 0.6 9.5 ± 0.5	159 ± 51.6 180 ± 62.4 220 ± 104 635 ± 123		2 ± 1.5 3.4 ± 3.3 14 ± 5.4 364.8 ± 195	3.5 ± 2.9 3.6 ± 1.9 7.4 ± 5.7 213 ± 157.6	
Yaseen and Scholz (2016; 2017a, b)	7.3 ± 0.1[e] 7.4 ± 0.1[f] 7.3 ± 0.1[g] 7.4 ± 0.1[h]	25 ± 0.6 9 ± 0.3 13 ± 0.8 14 ± 1		9.6 ± 0.5 9.3 ± 0.1 9.3 ± 0.2 9.4 ± 0.1	116 ± 4.5 122 ± 5.2 115 ± 5.2 116 ± 2.5		3.6 ± 1 5.5 ± 0.8 2.9 ± 0.6 3.3 ± 0.7	1.4 ± 0.4 1.9 ± 0.3 2.4 ± 0.3 1.5 ± 0.3	
Mountassir et al. (2015)	6.8	736	5.37		1500				320
Punzi et al. (2015)		590							
Verma et al. (2012, 2015)	7.5 ± 0.1	770 –790							
Aldoury et al. (2014)	6,7,8	650–900				370–550			
Aouni et al. (2012)	9.9[j] 10.5[k] 10.3[l]	566 450 470			2490 1407 2240				
Ong et al. (2010)		383.8 ± 13.7[m] 450 ± 8[n]							
Avlonitis et al. (2008)		180[p] 360[q] 360[r]			1500 2120 3070				
Bali and Karagozoglu (2007)		213							
Mbuligwe (2005)	10.68 ± 0.78	85.28 ± 6.5							
Kang et al. (2002)		250							
Panswad et al. (2001)	7.4–7.5	492–552							
Marquez and Costa (1996)	7.3	250 ± 30	1.44						

Parameter	N (mg/l)	P (mg/l)	NH_4–N (mg/l)	NO_3–N (mg/l)	Alkalinity (mg/l)	TKN (mg/l)	Sulphate (mg/l)	Colour (Pt–Co)	Dye (mg/l)
Yaseen and Scholz (2018)			0.24 0.19 0.22	0.58 0.48 0.53				571.4 254.7 411.5	
Hussein and Scholz (2017)									6.9 ± 3.3 209 ± 4.5 6.6 ± 1.8 222 ± 31.9

Table 6 (continued)

Parameter	N (mg/l)	P (mg/l)	NH_4–N (mg/l)	NO_3–N (mg/l)	Alkalinity (mg/l)	TKN (mg/l)	Sulphate (mg/l)	Colour (Pt–Co)	Dye (mg/l)
Yaseen and Scholz (2016; 2017a, b)								448 ± 30 171 ± 35 408 ± 11.8 676 ± 35	5 ± 0.3 5.1 ± 0.4 5 ± 0.3 5.1 ± 0.4
Mountassir et al. (2015)								0.8[i]	
Punzi et al. (2015)									
Verma et al. (2012, 2015)					1150–1130				
Aldoury et al. (2014)									
Aouni et al. (2012)								2.05[i] 1.92[i] 1.76[i]	
Ong et al. (2010)	55.4 ± 3.4 59 ± 2	6.7 ± 0.3 6.5 ± 0.3	34.8 ± 2.8 36 ± 4	29.5 ± 2.2 28 ± 2					51 ± 2 103 ± 3
Avlonitis et al. (2008)									130 260 230
Bali and Karagozoglu (2007)									
Mbuligwe (2005)							48.2 ± 7.7	100.2 ± 21.87	
Kang et al. (2002)								1050[s]	
Panswad et al. (2001)	25,50,70	5.3-15.5			444–762	24.8–72.3			
Marquez and Costa (1996)									

m1 mixture 1 (8 mg/l of basic red 46 + 2 mg/l of reactive blue 198), *m2* mixture 2 (2 mg/l of basic red 46 + 8 mg/l of reactive blue 198), *m3* mixture 3 (5 mg/l of basic red 46 + 5 mg/l of reactive blue 198)

[a]Dye basic red 46 at low concentration, [b]dye basic red 46 at high concentration, [c]dye acid blue 113 at low concentration, [d]dye acid blue 113 at high concentration, [e]dye acid blue 113, [f]dye reactive blue 198, [g]dye basic red 46, [h]dye direct orange 46, [i]colour based on the spectral absorption coefficient, [j]using the dye everzol black, [k]using the dye everzol blue, [l]using the dye everzol red, [m]at concentration of 50 mg/l, [n]at concentration of 100 mg/l, [p],[q] and [r], Bath 1, 2 and 3 respectively, [s]colour based on American dye manufacturer's institute unit

as a hydrolysis agent to control pH. This compound is important in the textile production process for producing covalent bonds between dyes and fabrics (Alaton et al. 2002). Researchers who have used these chemicals are mentioned in Table 5.

Sulphuric acid is a strong acid, which is widely used for pH control purposes as a neutralising agent. Sodium lauryl sulphate is used in textile wastewater constituents as a scouring agent (Verma et al. 2012).

Urea is one of the main chemicals applied in the printing process of the reactive dyes, causing a high pollutant load. It is an organic compound widely used as a fertiliser in the agricultural field due to its high nitrogen concentration. Many authors have used urea to simulate textile effluents (Marquez and Costa 1996; Panswad and Luangdilok 2000; Panswad et al. 2001).

Table 7 Proposed recipe simulating the textile effluents

Chemical name	Chemical formula	Molar mass (g/mol)	Concentration (mg/l)	Composition percentage (%)
Sodium benzoate	C_6H_5COONa	144.1	107.1	C (58.34), H (3.5), O (22.2), Na (15.95)
Sodium acetate	CH_3COONa	82.03	204.9	C (29.28), H (3.69), O (39.01), Na (28.02)
Ammonium nitrate	NH_4NO_3	80.04	27.1	N (35), H (5.04), O (59.96)
Sodium chloride	NaCl	58.44	7	Na (39.34), Cl (60.66)
Magnesium chloride hexahydrate	$MgCl_2{\cdot}6H_2O$	203.3	3.4	Mg (11.96), Cl (34.88), H (5.95), O (47.22)
Calcium chloride dihydrate	$CaCl_2{\cdot}2H_2O$	147.02	4	Ca (27.26), Cl (48.23), H (2.74), O (21.77)
Potassium hydrogen phosphate trihydrate	$K_2HPO_4{\cdot}3H_2O$	228.22	36.7	K (34.26), H (3.09), P (13.57), O (49.07)
Trace element stock solution[a]				
Boric acid	H_3BO_3	61.83	150	H (4.89), B (17.48), O (77.63)
Ferrous chloride	$FeCl_2$	126.75	1500	Fe (44.06), Cl (55.94)
Zinc chloride	$ZnCl_2$	136.29	120	Zn (47.97), Cl (52.03)
Manganese(II) chloride tetrahydrate	$MnCl_2{\cdot}4H_2O$	197.9	120	Mn (27.76), Cl (35.83), H (4.07), O (32.34)
Copper(II) chloride dihydrate	$CuCl_2{\cdot}2H_2O$	170.48	30	Cu (37.27), Cl (41.59), H (2.36), O (18.77)
Cobalt(II) chloride hexahydrate	$CoCl_2{\cdot}6H_2O$	237.93	150	Co (24.77), Cl (29.8), H (5.08), O (40.35)
Sodium molybdate	Na_2MoO_4	205.92	60	Na (22.33), Mo (46.59), O (31.08)
Potassium iodide	KI	166.00	30	K (23.55), I (76.45)

[a]1 ml of the trace element stock solution added to each 1 L of the ingredients mixture above, as proposed by Muda et al. (2010)

Boric acid is found in textile effluents as a boron ion. It is used in different concentrations for preparing synthetic textile wastewater (Table 5).

The main sources for trace elements in artificial wastewater are ferrous chloride, zinc chloride, manganese(II) chloride tetrahydrate, copper(II) chloride dehydrate, sodium molybdate, cobalt(II) chloride hexahydrate, potassium iodide, zinc sulphate heptahydrate, magnesium sulphate heptahydrate, copper(II) sulphate pentahydrate, manganese(II) chloride dehydrate, aluminium sulphate hexadecahydrate, calcium chloride dehydrate, cobalt(II) chloride hexahydrate and thiamine–hydrogen chloride. These chemicals have been used previously in different studies (Basibuyuk and Forster 1997; Mohan et al. 2002; Muda et al. 2010).

Evaluation and suggested constituents

A wide variety of ingredients and corresponding concentrations have been suggested in the literature for the simulation of textile effluent (Table 5) to simulate the effluent either in a particular country or a specific textile factory. However, some authors provided constituents, which were lower in chemical concentrations than the typical range of textile effluents. Therefore, it is important to evaluate these constituents and present them in a way that helps future researchers to decide which ingredients are most suitable for use in particular circumstances.

Note that the type of treatment, microbes used, the type of plant and their survival are important parameters, which should be decided on carefully, depending on the type of chemicals used and their corresponding concentrations in artificial wastewater constituents. Regarding biological treatment using a CW vegetated with emergent plants, the constituents reported upon by the researchers in Table 5 are suitable for use. Note that the wastewater constituents used by Hussein and Scholz (2017) contained fertiliser at a very low concentration, and the inflow COD values were within the typical range of the textile effluents (Ghaly et al. 2014) in the case of using a high dye concentration only, which means that the dye in the mixture was responsible for the high load of COD as clarified in Table 6.

Cumnan and Yimrattanabovorn (2012) as well as Ong et al. (2009, 2010) used mixture of ingredients rich in salts, nutrients, sodium and carbon sources for preparing artificial wastewater. The inflow parameters were within the typical range except for NO_3–N and NH_4–N concentrations, which were high. However, this mixture may require a source (ingredient) for the main heavy metals present in textile effluents.

Noonpui and Thiravetyan (2011) focused on including salt sources only in their synthetic wastewater. Ojstršek et al. (2007), and Bulc and Ojstršek (2008) provided constituents for three dye baths, and the COD values in all these baths were within the typical range. Mbuligwe (2005) provided a new constituent with a COD concentration lower than the typical values. However, the constituent reported by Keskinkan and Göksu (2007) contained low chemical concentrations using the hydroponic Arnon-Hoagland nutrient solution after dilution. Submerged plants were suitable for

treatment by this constituent. Yaseen and Scholz (2016) also dealt with low chemical concentrations using TNC aquatic plant fertiliser treated by free-floating plants and/or algae. The characteristics of the inflow were lower than the typical range except for the colour and pH values. The authors suggested using this constituent in the case of operating a polishing treatment stage.

Regarding the anaerobic/aerobic or anoxic/aerobic sequential batch reactor methods, the ingredients suggested by Marquez and Costa (1996), Basibuyuk and Forster (1997), Panswad and Luangdilok (2000), Panswad et al. (2001), Khehra et al. (2006), Muda et al. (2010), Aldoury et al. (2014) and Al-Amrani et al. (2014) were more appropriate for use, because their constituents included most of the chemicals that are essential in simulating textile effluents, compared with the constituents reported on by Nopkhuntod et al. (2012) and Punzi et al. (2015).

Well-defined ingredient-based constituents suitable for use with physical and chemical methods of treatment have been proposed, previously (Alaton et al. 2002; Avlonitis et al. 2008; Aouni et al. 2012; Mountassir et al. 2015). However, the composition reported by Verma et al. (2012, 2015) is the most appropriate one due to the presence of most of the chemicals used in textile processing. However, the addition of a source of trace elements, such as the solution provided in Table 7, is suggested to fully simulate the artificial wastewater compounds.

This review suggests using constituents within the typical range of textile effluents. The composition contains nutrients, salts, trace elements and carbon sources (Table 7). The dye concentration used in this composition depends on the stage of the specific treatment applied; i.e. primary, secondary or tertiary. The proposed composition of constituents (Table 7) is suitable for use in biological treatment systems such as wetlands with emergent plants. However, in order to ensure the survival of *L. minor* and algae, a dilution of at least around 1 part of synthetic textile wastewater to 24 parts of raw water (Yaseen and Scholz 2018) is required.

Conclusion

The textile industry is one of the larger consumers of potable water and, consequently, produces a huge amount of wastewater. Although the typical characteristics of textile factory wastewaters have been previously documented, the real effluents from different textile mills presented in studies vary widely and some of the characteristic parameter values are not within typical ranges. Textile effluents are undesirable, and their treatment is extensively required for environmental protection, but also for reuse purposes. Various biological, physical and chemical methods have been examined and used for the treatment of real textile and dyeing effluents.

This article summarised the available characteristics of different textile mill effluents and the constituents used by authors for the preparation of simulated textile wastewater. These constituents contained different chemicals, which may be toxic to the specific microbes or plants in the treatment system, due to the chemical toxicity itself or due to the high concentration of these compounds. Therefore, this review organised the reported constituents depending on the system of treatment applied and evaluated their components based on the typical characteristics of textile discharges. The authors also suggested ingredients for a new mixture to simulate textile effluents. The proposed mixture contains the main textile factory pollutants.

Further research is needed to summarise and evaluate the efficiency of the methods applied to treat real and artificial textile wastewater containing complex dye mixtures. Also, it is necessary to focus on comparing the removal efficiency of each textile dye separately and in common mixtures, as this area of research remains limited. In addition, further studies are required to focus on metal pollutants in textile effluents and the methods applied for their treatment.

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Compliance with ethical standards

Conflict of interest The authors have declared no conflict of interest.

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